# TECHNICAL REPORT

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| Contract Title: | Infrared Algorithm Development for Ocean Observations with EOS/MODIS |
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| Type of Report: | Semi-annual |
| Time Period: | July-December 1996 |
| Principal Investigator: | Otis B. Brown<br>RSMAS/MPO<br>University of Miami<br>4600 Rickenbacker Causeway<br>Miami, Florida 33149-1098 |

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## INFRARED ALGORITHM DEVELOPMENT FOR OCEAN OBSERVATIONS WITH EOS/MODIS


### Abstract

Efforts continue under this contract to develop algorithms for the computation of sea surface temperature (SST) from MODIS infrared retrievals. This effort includes radiative transfer modeling, comparison of *in situ* and satellite observations, development and evaluation of processing and networking methodologies for algorithm computation and data accession, evaluation of surface validation approaches for IR radiances, and participation in MODIS (project) related activities. Efforts in this contract period have focused on radiative transfer modeling, evaluation of atmospheric correction methodologies, analysis of field data, production and evaluation of new computer networking strategies, objective analysis approaches, revision of the ATBD and participation in the ATBD review process, and participation in MODIS meetings.


## MODIS INFRARED ALGORITHM DEVELOPMENT

### A. Near Term Objectives

A.1. Continue algorithmic development efforts based on experimental match-up databases and radiative transfer models.

A.2. Continue interaction with the MODIS Instrument Team through meetings and electronic communications, and provide support for MCST pre-launch calibration activities.

A.3 Continue evaluation of different approaches for global SST data assimilation and work on statistically based objective analysis approaches.

A.4 Continue evaluation of high-speed network interconnection technologies.

A.5 Continue evaluation of various *in situ* validation approaches for the MODIS IR bands.

A.6 Provide investigator and staff support for the preceding items.

## B. Overview of Current Progress

### B.1 July-December 1996

Activities during the past six months have continued on the previously initiated tasks. There have been specific continuing efforts in the areas of (a) radiative transfer modeling, (b) generation of model based retrieval algorithms, (c) continued work on IR calibration/validation as part of the MODIS Ocean Science Team cruise effort, d) analysis of consequences of imperfect pre-launch characterization of the MODIS infrared channels, and (e) work on test and evaluation of an experimental wide area network based on ATM technology. In addition previously initiated activities such as team related activities continue.

Special foci during this six month period have been:

1) continue exploring sources of radiosondes to compile a global marine data set that correctly represents the distributions of conditions in the atmosphere,
2) AVHRR *in situ* comparison data base studies.
3) analysis of measurements from the DOE/NOAA/NASA ARM Combined Sensor Project cruise in the Tropical Western Pacific in the spring of 1996.
4) Revise the MODIS Infrared Sea Surface Temperature ATBD (ATBD-MOD-25) and participate in the ATBD review process.
5) Construction of a marine FTIR instrument for cal/val applications by UW/SSEC via subcontract .
6) Submit proposals for ship-time for post-launch validation, and explore options for long-term validation for fixed platforms.

#### B.1.1 Radiative Transfer Modeling

Dr. Richard Sikorski has been modeling emitted and reflected infrared radiation at the top of the atmosphere, for the simulation of the brightness temperatures (BTs) measured by satellite instruments with various spectral sensitivities.

During the repeated measurements and calibrations of the MODIS instrument, discrepancies have arisen between various methods of determining the relative spectral responses (RSRs) of the thermal IR bands, and between subsequent generations of SBRS-reported RSRs. To study the impact of these discrepancies on the MODIS thermal IR error budget, a modified version of the RAL model was run with five distinct atmospheres: high latitude sites with low moisture, low latitude sites with high moisture, and mid-latitude sites with a variety of vapor profiles. Studies of the differences between various SBRS-produced RSRs were made for bands 31 and 32 versus zenith angle and versus total water vapor load. The contributions to top-of-atmosphere radiance were studied for surface-leaving radiance, atmospheric radiance, and reflected radiance, versus zenith angle and versus total water vapor load. Studies were conducted of the temperature deficits (BT-SST) of bands 20, 31 and 32 versus latitude and zenith angle.

The impact of uncertainties in the IR band characterizations continues to be a cause of concern. The total thermal IR error budget can be consumed by the difference between component-level and system-level measurements of the RSRs for bands 31 and 32. The uncertainties will be zenith angle dependent, vapor load dependent, and vertical-structure dependent, with considerable sensitivity to features such as low-altitude inversions or long pathlengths through moist atmospheres.

Modifications of the RAL model are under way to quantify the impact of various MODIS instrumental uncertainties on the error budget, and to develop a pre-launch SST algorithm.

B.1.2 Algorithm Development Efforts Based on Experimental Match-up Data bases

During this period we have continued the compilation of *in situ* sea surface temperature (SST) data from moored and drifting buoys in order to build a co-temporal, co-located set of *in situ* and AVHRR data. The "matchups" are being used to estimate SST algorithm coefficients and to characterize algorithm performance.

We have experimented with numerous alternative formulations for an AVHRR SST algorithm. In close collaboration with the SST Science Working Group, we have defined a consensus algorithm. The algorithm is based on the non-linear SST formulation (NLSST) originally proposed by C. Walton (NOAA-NESDIS). In order to minimize temporal trends detected in the residuals (defined as *in situ* minus satellite SST), the algorithm coefficients are estimated on a monthly basis, using matchups for a 5-month window centered on the month for which coefficients are being estimated. The performance of the algorithm is being assessed in relation to reference fields such as the Reynolds Optimally Interpolated (OI) fields. Results suggest that, in some regions, there may be errors in the retrievals associated with atmospheric aerosols. Examples of this are the eastern tropical Atlantic and the northern Indian Ocean.

Dr. P. Minnett attended a Workshop on Atmospheric Aerosols within the framework of the ARM program at Oak Ridge National Laboratory in November. The interests of other participants, however, were in radiative effects of aerosols in the visible or near infrared ($\lambda$<~2μm), and no one was able to suggest useful leads for studying aerosol effects at wavelengths of 10-12μm. Useful discussions were held with Dr. T. Charloch (NASA Langley Research Center) who has provided some results of numerical simulations in this region. These will form the initial guidance to studying the aerosol effects in the longer wavelengths of interest to MODIS.

B.1.3 The Combined Sensor Cruise of the NOAA ship Discoverer

As reported in the last semi-annual report, Dr. Peter Minnett participated in the Combined Sensor Cruise of the NOAA Ship Discoverer in the Tropical Western Pacific from mid-March to mid-April, 1996.

One of the objectives of this cruise was to test the use of the prototype Marine-Atmosphere Emitted Radiance Interferometer (M-AERI), which will be a key instrument in the post-launch validation of the infrared channels of MODIS, and of the derived Sea-Surface temperature (SST) corrected for the effects of the intervening atmosphere. The area of the cruise included the "warm-pool" of the tropical Pacific where both the SST and the atmospheric water-vapor loading exhibit global maxima. Thus the cruise conditions are at a climatological extreme. The high air temperatures and strong insolation also meant that the instruments were being stressed towards their upper operating temperatures.

Analysis of the M-AERI skin temperature measurements has revealed significant, but anticipated, differences with respect to the *in situ* bulk temperatures. Examining these as a function of local sun time reveals the skin temperature oscillating about the bulk temperature with a diurnal cycle, being colder at night and warmer during the day. Even though there is considerable variability along the Equatorial Section from day to day, as meteorological conditions evolve, and within a day, as a result of spatial as well as temporal changes, the mean temperature discrepancies behave in a physically reasonable manner. During the day, when windspeeds are low, the absorption of the sun's energy in the upper several meters of the ocean generates a vertical temperature gradient that causes the bulk temperature just below the ocean surface to be higher than at the 5m depth where the *in situ* measurements in these figures were made. The heat loss from the oceans to the atmosphere, caused primarily by evaporation, results in a temperature difference across the molecular conducting layer with the skin temperature being cooler than the subsurface *in situ* temperature. Nevertheless the skin temperature difference is smaller than the bulk gradients resulting in the skin temperature being warmer than the 5m bulk temperature. (See Figures in the July-September 1996 Quarterly Report)

B.1.4 Future validation campaign planning

Space has been offered to Dr. Minnett on the Canadian ice-breaking research vessel *Louis S. St.-Laurent* on cruises to the Arctic in summer 1997 and 1998. These cruises, to the north of Baffin Bay, are subject to approval of funding by the Canadian Natural Sciences and Engineering Research Council. Assuming they will take place, they provide the first opportunity for using M-AERI in polar regions and for testing MODIS validation procedures for high-latitude conditions.

An additional proposal has been submitted to the Alfred-Wegener Institute for Polar and Marine Research in Germany to make use of their ice-breaking research vessel *Polarstern* in the MODIS post-launch validation campaigns. This vessel makes annual cruises from Germany to Antarctica through the Atlantic Ocean and thereby provides an excellent opportunity for making validation measurements through a wide range of climate conditions. Similarly the US Coast Guard icebreakers make a supply voyage from Seattle to Antarctica each year; space on these vessels has also been requested. The initial responses from both organizations has been favorable, but no firm commitments have been made.

Part of the MODIS SST validation strategy is to deploy an M-AERI on a fixed platform for an extended period (months to a year). This will allow a longer time series of validation data to be constructed than is possible from a ship. A number of potentially suitable platforms have been identified, including some along the US East and Gulf Coasts, in the North Sea, in the Mediterranean Sea, and in the Indian Ocean off Western Australia. Of these, those off Australia offer the best opportunity to sample oceanic conditions, and through tropical atmospheres which present a particularly difficult atmospheric correction. Also, the proximity of Curtin University of Technology in Perth provides a basis for local support for routine monitoring of the state of the instruments. There are problems associated with these platforms however; they are there for oil or gas extractions and therefore present issues regarding cleanliness and safety. They are also quite remote and, those that are far from land, quite difficult to reach. Efforts are continuing to identify suitable locations for post-launch validation.

B.1.5 Analyses in support of MODIS infrared channels pre-launch calibration and characterization

In addition to the radiative transfer modeling to simulate the consequences of uncertainties in the spectral characterization of the MODIS infrared channels (see B.1.1), analyses have been conducted to quantify the effects of uncertainties in the instrument properties. Amongst these is the dependence of the scan mirror reflectivity, and infrared emissivity, on angle, wavelength and polarization. An analysis has shown that uncertainties in the scan mirror reflectivity of 0.1% can lead to worst case errors in retrieved SST of 0.6K. This is twice the total target uncertainty in SST. Similarly, uncertainties in the scan mirror temperature of >1K would lead to unacceptable errors in the derived SST.

B.1.6 Wide Area Networking

Two Digital Equipment Corp. 4100s have been added to the ATM networks since the last report. The ATM networks are functioning well. Additional enhancements are in process and should be implemented by the end of the next quarter. The current network includes FORE, Digital and SGI hardware, which is all interoperating.

B.1.7 Documentation

The MODIS Infrared Sea Surface Temperature Algorithm Technical Basis Document (ATBD-MOD-25; available from http://www.rsmas.miami.edu/modis in pdf or ps formats) was revised and presented at the ATBD Review on November 20, 1996. The revisions to the ATBD include the adoption of a non-linear atmospheric correction algorithm, based on the widely-accepted NLSST (Non-Linear Sea Surface Temperature) algorithm currently used with AVHRR measurements. The post-launch validation strategy is described in detail in the revised ATBD. No serious criticisms were raised during the ATBD review process.

## C. Investigator Support

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| **July** | W. Baringer<br>O. Brown<br>P. Evans | **October** | W. Baringer<br>O. Brown<br>V. Halliwell<br>J. Hanafin<br>D. Wilson-Diaz |
| **August** | W. Baringer<br>O. Brown | **November** | W. Baringer<br>O. Brown<br>P. Evans<br>V. Halliwell<br>J. Hanafin<br>D. Wilson-Diaz |
| **September** | W. Baringer<br>O. Brown<br>P. Evans | **December** | O. Brown<br>J. Hanafin<br>D. Wilson-Diaz |

## D. Future Activities

D.1 Current:

D.1.1 Algorithms

a. Continue to develop and test algorithms on global retrievals
b. Evaluation of global data assimilation statistics for SST fields
c. Continue radiative transfer modeling using RAL code
d. Continue analysis of Combined Sensor Cruise, data
e. Continue to study near-surface temperature gradients
f. Continue planning of post-launch validation campaigns.
g. Validation Plan updates (as needed)
h. EOS Science Plan updates (as needed)
i. Define and implement an extended ATM based network test bed
j. Evaluate and analyze results of calibration/validation experiment
k. Continued integration of new workstations into algorithm development environment
l. Continued participation in MODIS Team activities and calibration working group.

D.1.2 Investigator support

Continue current efforts

## E. Problems

No new problems to report.

## F. Publications and Presentations

Minnett, P.J. and R.H. Evans. Evidence of effects of aerosols on thermal infrared measurements from satellites. Presented at the 2nd ARM Aerosol Workshop, November 1996, Oak Ridge National Laboratory, Oak Ridge, TN.

Evans, R.H. and G. Podestá. AVHRR Pathfinder: SST Approach and Results. AGU Fall Meeting, December 1996, San Francisco, CA.

Knuteson, R.O., F.A. Best, H.B. Howell, P. Minnett, H.E. Revercomb, and W.L. Smith. High Spectral Resolution Infrared Observations at the Ocean-Atmosphere Interface in the Tropical Western Pacific using a Marine Atmospheric Emitted Radiance Interferometer (MAERI): Applications to SST Validation and Atmospheric Spectroscopy. Accepted for presentation at the Ninth Conference on Atmospheric Radiation, 2-7 February 1997, Long Beach, CA.

Minnett, P.J. and R.O. Knueteson. Measurements of the Thermal skin effect and diurnal thermocline in the tropical Pacific Ocean. Accepted for the 7th Science Team Meeting of the Atmospheric Radiation Measurements Program, March 1997, San Antonio, TX.